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THE EFFICIENCY OF A CROSS-RIBBED CURVILINEAR DIFFUSER

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In one of our reference papers [1] a method is given for increasing the efficiency of a diffuser by installing especially designed cross-ribbing on its walls. The results were obtained for diffusers with rectilinear generatrices and for relatively small Re numbers ($Re < 10^5$). We know that in the presence of various turbulators: roughness and concentrated protuberance on the surfaces of poorly streamlined bodies (cylinders, balls, etc.) the hydraulic resistance of a device diminishes within a certain relatively narrow range of Re numbers; with a further increase in Re this effect disappears and the resistance of the body with the turbulator becomes greater than without it.

Fudge and Worsep [2] performed experiments with a cylinder on the surface of which wires of different diameter were located parallel to the generatrices near the point of minimum pressure. It was shown that with an increase in Re the effect caused by the use of a turbulator decreases and for $Re > 2 \cdot 10^5$ the resistance of the cylinder with the turbulators becomes greater than without them.

This phenomenon is, as we know, explained by forced turbulation of the laminar boundary layer, as a result of which there occurs a breakaway not of the laminar, but

the turbulent layer, which is capable of overcoming larger positive pressure gradients without breakaway. The turbulation referred to is efficient for relatively low values of Re, when the overall level of turbulence is low. With an increase in Re the overall level of turbulence is raised and the artificial turbulization becomes inefficient.

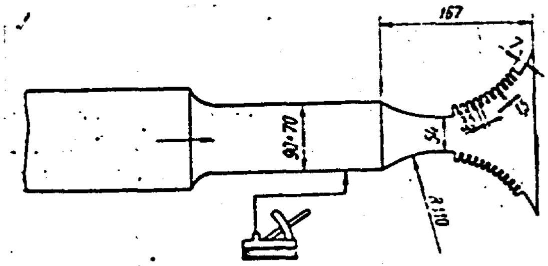

Fig. 1. Diagram of the experimental apparatus.

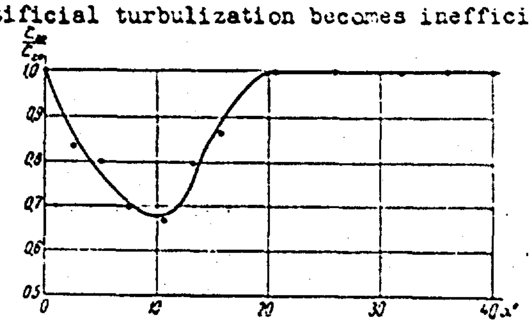

Fig. 2. Influence of the arrangement of the rib system.

It was extremely important, therefore, to study the cross-ribbed diffuser at high values of Re, corresponding to the operating conditions for diffusers in turbines. It was also important to investigate the efficiency of cross ribbing for a curvilinear diffuser. The investigations were conducted on a plane curvilinear diffuser model, the generatrices of which were constructed in the form of an arc of a circle. Such a curvature was provided in order to demonstrate the possibility of using cross-ribbing for prolonging high-intensity breakaway.

A diagram of the experimental apparatus is shown in Fig. 1. The flow from the pressure line of the blower enters into the confuser, which provides a uniform field of velocities, and then passes through the straight portion into the curvilinear channel. The static pressure was measured at six drainage apertures located on the perimeter of a rectangle. The outlets were joined into a single tube and led off to a micromanometer. The velocities of the flow were determined with a Prandtl tube and averaged. The inter-rib cavities along the generatrices of the diffuser were cut to a depth of 7 mm. In constructing the ribs 1.5 mm in thickness with a

distance of 3.5 mm between them we were keeping to recommendations for the selection of optimal ribbing derived in experiments on rectilinear diffusers. In the first approximation the height of a rib h and the distance between ribs s are related by the equation $s \approx 0.5h$. We shall again note that the stated relationships are tentative. In the experiments the location of the rib system on the generatrices of the diffuser was varied. It was shown that the efficiency of the diffuser ribbing depends upon the location of the first inter-rib cavity along the flow. In these experiments the rib system was composed of 15 ribs. It was observed that the first inter-rib cavity for which the cross-ribbing lessens the resistance of the device is located a short distance downstream from the narrow section. Displacement of this inter-rib cavity along with the whole rib system up or downstream from the stated section causes the cross-ribbing to become inefficient. The results of these experiments are listed in Fig. 2. The losses were evaluated in terms of the resistance coefficient $\zeta = \frac{\Delta p}{\rho \frac{w^2}{2}}$. Here atmospheric pressure is taken as the counterpressure, and w is the velocity in the narrow section. Twice the radius of curvature of the diffuser was taken as the characteristic dimension in the expression for Re. Plotted along the abscissa is the central angle measured from the vertical diameter (passing through the narrow portion of the canal) to the diameter passing through the origin of the first inter-rib cavity (the condition $\alpha = 0$ corresponds to the case in which the first inter-rib cavity is situated in the narrow portion of the channel). As can be seen from the graph, the maximum effect occurs when $\alpha = 8^\circ$ to 12°. It is necessary to assume that this narrow region is situated before the breakaway point. When the first inter-rib cavity is situated downstream beyond the breakaway point, the inter-rib cavities are not streamlined by the active boundary layer, and the effect of the ribbing disappears.

We note that the cross-ribbing being used is organized in such a way that the upper ends of the ribs are inscribed in an initally smooth surface. Such surfaces are usually called semismooth surfaces.

Depicted in Fig. 3 is the dependence of the resistance coefficient of the diffuser on Re for the optimal position of the first inter-rib cavity. The maximum velocity at the diffuser intake is ~110 m/sec. We note that this resistance coefficient is not the resistance coefficient proper to the diffuser, since it incorporates the resistance of the supplying confuser device. However, since this resistance was constant for all the experiments, the parameter we have adopted indirectly determines the diffuser resistance. As can be seen from the graph, the installation of cross-ribbing reduces the diffuser resistance coefficient by one third. This attests to the high efficiency of this type of ribbing for flow-separation diffusers. The fact that the resistance coefficient is independent of Re merits attention. A comparison between the data in Fig. 3 and the reference article [2] shows that the effect of cross-ribs is not identical to the effect of ordinary turbulators. As was noted, when ordinary turbulators are used, an increase in Re leads to their becoming inefficient; for the case of cross-ribs the efficiency does not vary with the Re number (except for the region of small Re); this is very important under the conditions present in turbines. Thus, the effect due to the use of cross-ribs cannot be explained from the point of view of a resistance crisis due to the forced transformation of the laminar boundary layer into a turbulent one.

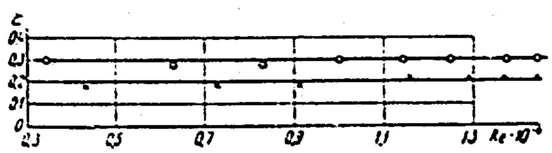

Fig. 3. Efficiency of curvilinear diffusers: O) smooth X) ribbed diffuser.

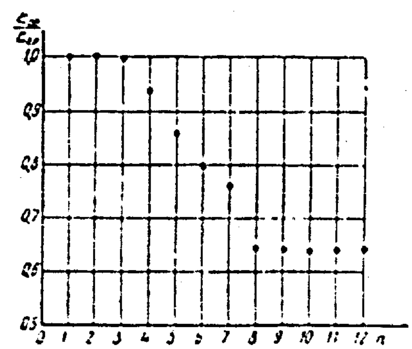

Fig. 4. The influence of the number of ribs on the efficiency of a diffuser.

The mechanism of this effect requires further investigation.

Experiments were conducted on the influence of the number of ribs, the first inter-rib cavity being situated in the optimal way. The number of ribs n downstream was varied. The results of the experiments are given in Fig. 4, from which it follows that for n > 8 the efficiency of the device does not change.

Thus, there is no necessity to cover the entire surface of the flow section with ribs; it is enough to install a definite and relatively limited number of them. This conclusion agrees with the result obtained for a ribbed diffuser with rectilinear generatrices

It is possible to draw the following conclusions from the work we have performed:

1. Cross-ribbing installed on the walls of curvilinear diffusers leads to an increase in their efficiency.

2. The efficiency of a ribbed diffuser significantly depends upon the arrangement of the ribs in the flow section.

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1. V. K. Migay. A Cross-ribbed Diffuser, Energomashinostroyeniye, 1960, No. 4.

2. The Current State of the Hydroaerodynamics of Viscous Fluids, Vol. 2, State Foreign Lit. Press, 1948.

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